A Heuristics Algorithm for Centralized Deicing Scheduling Problem

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Abstract. For the solution of the deicing delay, the greedy randomized adaptive search procedure (GRASP) was applied to optimize the scheduling scheme. Based on the simulation software, the departure data of an international airport was used to verify the validity of the proposed algorithm and compare the simulation results with the first-come, first-served (FCFS), greedy without availability check (GWOAC), and greedy with availability check (GWAC). In the model, the cost of the deicing time window, the deicing queue time and the moving distances of aircraft were included in the objective function. The simulation experiments on 283 instances results show that GRASP outperforms other algorithms on aircraft deicing queue time and take-off delay time. Furthermore, in order to obtain an optimal scheduling scheme, vehicles' workload is balanced by adjusting the model after evaluating the working hours of each deicing vehicle.

Introduction

Cold and snowy weather in winter can cause freezing on aircraft surface, resulting in loss of aircraft lift and endangering aviation safety. Such a thin layer of frost or ice may cause crash. As one of the key issues, aircraft ground deicing is necessary before taking off and the efficiency of it has a direct impact on the punctuality rate of flights.

Three deicing methods are now used at the airport. Due to the low efficiency of decentralized deicing and the difficulty of slow deicing, this paper focuses on centralized deicing. This way of deicing means selecting a specific location and placing the deicing area beside the runway entrance. All aircraft need to be deiced will move to this area before taking off.

In recent years, with the rapid development of civil aviation industry and the substantial increasing of flight density, how to efficiently and rationally optimize the dispatch of vehicles becomes an urgent problem. It is very important to establish a reasonable and efficient scheduling strategy for centralized deicing vehicles.

Aircraft ground deicing is a complex nonlinear programming problem. The process is dynamic and strongly coupled, which can be reduced to a kind of resource scheduling problem with environment change. At present, the research on deicing and dispatching is still in infancy.

To alleviate the flight delay, Zhiwei Xing [1] established a multi-deicing model based on non-cooperative game theory. Wei Zhang [2] proposed a heuristic scheduling model based on game allocation scheme. Yuming Zou [3] and Junyi Wang [4] respectively used queuing theory and genetic algorithm to solve the scheduling problem, and Taipeng Yang [5] used multi-agent technology. Norin A. [6] studied a greedy randomized adaptive search procedure to optimize the path of the deicing vehicles, aiming to shorten the total journey of vehicles.

The above literatures used some algorithms to solve the scheduling problem and optimize it as much as possible. But the workload of vehicles and deicing queue time of aircraft are not taken into account.

Based on the above-mentioned researches, the process of centralized deicing is analyzed in this paper. As the aircraft deicing queue time and moving distances the main goal, this paper uses greedy randomized adaptive search procedure (GRASP) to obtain an optimal scheduling scheme. Simulation experiments verify the reliability of the proposed algorithm. Considering the working time of each vehicle, some adjust is done for the balance of the workload.

Airport Centralized Deicing Scheduling Model

Deicing Process

The deicing process is showed in Figure 1. Aircraft depart from the terminal to the deicing apron and proceed to the runway entrance for departure after deicing. The vehicles start from the garage and work on the deicing apron.

Model Hypothesis

- In the initial stage, vehicles are in a full liquid state and vehicles and aircraft are in their designated position.
- The number of deicing locations and vehicles are limited and known.
- The distances between apron, deicing apron, garage, refueling station and the runway entrance are known.
- The deicing process of an aircraft cannot be interrupted.
- The breakdown of vehicles, the rest of the staff, the heating time of the deicer, the landing, take-off process and secondary deicing is not considered in this model.

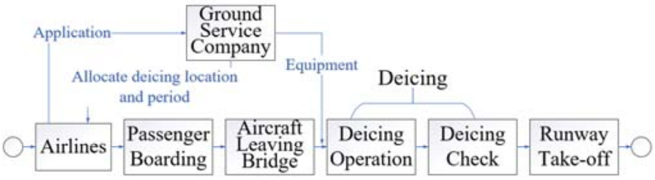


Figure 1. Aircraft deicing process

Symbolic Variable Declaration

Suppose p_i aircraft need to be deiced, $i = 1,2,\mathrm{L}\ ,I$; there are v_j vehicles in the model that can be used, $j = 1,2,\mathrm{L}\ ,J$; each aircraft needs k vehicles; D_s deicing locations in the deicing apron, $s = 1,2,\mathrm{L}\ ,S$; S_r locations in the apron, $r = 1,2,\cdots,R$ $r = 1,2,\mathrm{L}\ ,R$; the upper capacity of each vehicle is Q , and the residual capacity of each vehicle is Q_j ; the deicer required for each aircraft is q_i ; v is the spraying rate of the deicer; STD_i indicates the estimated departure time of aircraft; $L(v_j)$ represents the task list of vehicle v_j ; f_i represents the time when the vehicle completes the task; T_j represents the working time of each vehicle.

Time Node. $T_{fs}(p_i)$ is the earliest deicing start time allowed by the aircraft; $T_{ls}(p_i)$ is the latest deicing start time allowed by the aircraft; $T_{a1}(p_i)$ is the time for waiting deicing location; $T_{a2}(p_i)$ is the time for waiting deicing vehicles; $T_{d1}(p_i)$ is the time when deicing starts; $T_{d2}(p_i)$ is the time when deicing ends; $T_{le}(p_i)$ is the time when the aircraft leave the deicing apron.

Period of Time. $t_{DD}(ss)$ is the distance(time) between deicing locations; $t_{SD}(rs)$ is the distance(time) between the apron and deicing locations; $t_{DR}(s)$ is the distance(time) between deicing locations and the runway entrance; $t_{cu}(v_j)$ represents the time when the vehicle v_j completes the current task or refueling.

Decision Variables. x_{is} is whether the aircraft p_i has reached the deicing location D_s which is expected to be allocated; y_{ij} is whether the vehicle v_j deices for the aircraft p_i .

Two penalty weight of the aircraft deicing time window are a_1 and a_2 ; b_1 is the penalty weight of deicing queuing; b_2 is the penalty weight of aircraft waiting take-off time.

The Optimization Goal

The deicing time window is $\left[T_{fs}\left(p_i\right),T_{ls}\left(p_i\right)\right]$, if the aircraft arrive at the deicing location earlier than the time $T_{fs}\left(p_i\right)$, waiting cost $\sum_{i=1}^{n}a_1\times\left(T_{fs}\left(p_i\right)-T_{d1}\left(p_i\right)\right)$ will be generated; if vehicles arrive later than the time $T_{ls}\left(p_i\right)$, delay cost $\sum_{i=1}^{n}a_2\times\left(T_{d1}\left(p_i\right)-T_{ls}\left(p_i\right)\right)$ will be generated. In order to minimize the total cost of the deicing time window, the objective function is established:

$$MinZ_1=\sum_{i=1}^{n}a_1\times\left(T_{fs}\left(p_i\right)-T_{d1}\left(p_i\right)\right)+\sum_{i=1}^{n}a_2\times\left(T_{d1}\left(p_i\right)-T_{ls}\left(p_i\right)\right) \tag{1}$$

If the aircraft wait outside the deicing apron, the deicing waiting cost $\sum_{i=1}^{n}b_1\times\left(T_{d1}\left(p_i\right)-T_{a1}\left(p_i\right)\right)$ will be generated; after deicing, if the aircraft take off after STD_i due to waiting, the waiting cost $\sum_{i=1}^{n}b_2\times\left(STD_i-T_{d2}\left(p_i\right)\right)$ will be generated. The minimum waiting cost function is established:

$$MinZ_2=\sum_{i=1}^{n}b_1\times\left(T_{d1}\left(p_i\right)-T_{a1}\left(p_i\right)\right)+\sum_{i=1}^{n}b_2\times\left(STD_i-T_{d2}\left(p_i\right)\right) \tag{2}$$

The minimum objective function of aircraft’s moving distances:

$$MinZ_3=\sum_{i=1}^{n}t_{SD}\left(rs\right)\times x_{is}+\sum_{i=1}^{n}t_{DR}\left(s\right) \tag{3}$$

Aircraft total objective function:

$$MinZ=MinZ_1+MinZ_2+MinZ_3 \tag{4}$$

During the deicing process, the number of tasks scheduled for each vehicle may be different, which may cause more working hours or more rest hours. In order to balance the working hours for deicing vehicle, the scheduling scheme needs to be adjusted. The working time function of each vehicle is:

$$T_j=\frac{Q_j}{v\sum_{j=1}^{m}y_{ij}} \tag{5}$$

Constraints:

$$\sum_{i=1}^{n}q_i z_{ij}\le Q,\ j=1,2,\cdots J \tag{6}$$

$$x_{is}=0 \quad or \quad 1 \tag{7}$$

$$y_{ij}=0 \quad or \quad 1 \tag{8}$$

$$\sum_{i=1}^{n}y_{ij}=k \tag{9}$$

$$T_{l2}\left(p_i\right)+t_{DR}\left(s\right)\le STD_i \tag{10}$$

Formula (4) is the total objective function, includes the cost of deicing window, the cost of deicing waiting and the sum of moving distances. Formula (6) indicates that the capacity of each vehicle limits the number of times the aircraft is serviced. Formula (7) indicates that if the aircraft p_i arrives at the designated D_s is 1, otherwise it is 0. Formula (8) indicates that if the aircraft p_i is deiced by vehicle v_j is 1, otherwise it is 0. Formula (9) indicates that each aircraft is serviced by k vehicles. Formula (10) indicates that departure time exceeds expected departure time STD_i.

Algorithms for Deicing Scheduling

Aircraft ground deicing is usually based on the order in which the aircraft arrive. This arrangement often leads to improper assignment, resulting in more delayed flights. Here, algorithm FCFS, GWOAC, GWAC, and GRASP [6][7] are proposed to solve the deicing schedule. The ultimate goal is to make the vehicle deicing process as soon as possible.

First Come First Served

The first-come first-served schedule is based on the rules of the airport operation, and tasks are arranged in the order which the aircraft come.

Greedy Without Availability Check

In this algorithm, the deicing mission is performed by the currently nearest vehicle, without checking whether or not the vehicle will be available. Sort v_j by $t_{DD}(ss)$ in ascending order for each aircraft, once vehicles complete its current assignments, move v_j to the location of p_i and update $L(v_j)$.

Greedy With Availability Check

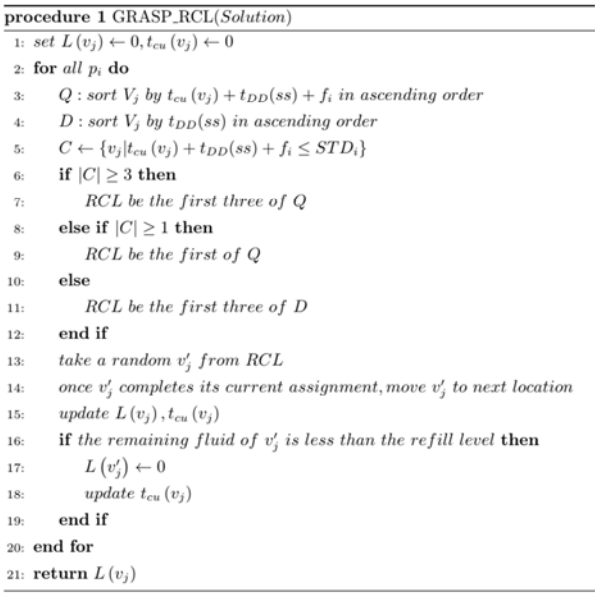
When choosing a deicing vehicle, consider whether or not the aircraft will take off on time. Sort v_j by $t_{cu}(v_j)+t_{DD}(ss)+f_i$ in ascending order, move v_j to next the assignment location and update $L(v_j)$ as well.

Greedy Randomized Adaptive Search Procedure

GRASP is a multi-step iterative algorithm, each iteration contains two stages [8]. The first stage is to construct a preliminary feasible solution. The feasible solution X and candidate set C are initialized to determine whether the restricted candidate list (RCL) could be entered. An element is randomly selected from RCL and adds to X until the condition is not met. The second stage is partial search, when the adjacent solution is better than X, replace it with the adjacent solution until there is no better solution in the domain. At the same time, set C is updated. The greedy function g, RCL, and parameter α are three important factors in this stage.

In the model, RCL consists of at least three vehicles that can reach the next assignment in time. If the number of available vehicles is less than three, RCL consists of one or two vehicles. If the number is 0, RCL consists of the three closest vehicles. The vehicle is randomly selected from RCL to obtain a preliminary feasible solution.

Two domain optimization methods are adopted in the model. The first is to swap any two items in $L(v_j)$. If the total duration $\cos t(v_j)$ is shorter, exchange assignments. Optimize the aircraft within an hour of the departure time interval. The second way is to delete an item in v_1 task list and add it to v_2 . If the new $L(v_j)$ takes less time, delete it. Construct preliminary feasible solution pseudo-code is shown in Figure 2, partial search pseudo-code is shown in Figure 3.



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procedure 1 GRASP_RCL(Solution)
set $L(v_j) \leftarrow 0, t_{cu}(v_j) \leftarrow 0$
for all $p_i$ do
    $Q$ : sort $V_j$ by $t_{cu}(v_j) + t_{DD}(ss) + f_i$ in ascending order
    $D$ : sort $V_j$ by $t_{DD}(ss)$ in ascending order
    $C \leftarrow \{v_j | t_{cu}(v_j) + t_{DD}(ss) + f_i \leq STD_i\}$
    if $|C| \geq 3$ then
        $RCL$ be the first three of $Q$
    else if $|C| \geq 1$ then
        $RCL$ be the first of $Q$
    else
        $RCL$ be the first three of $D$
    end if
    take a random $v'_j$ from $RCL$
    once $v'_j$ completes its current assignment, move $v'_j$ to next location
    update $L(v_j), t_{cu}(v_j)$
    if the remaining fluid of $v'_j$ is less than the refill level then
        $L(v'_j) \leftarrow 0$
        update $t_{cu}(v_j)$
    end if
end for
return $L(v_j)$
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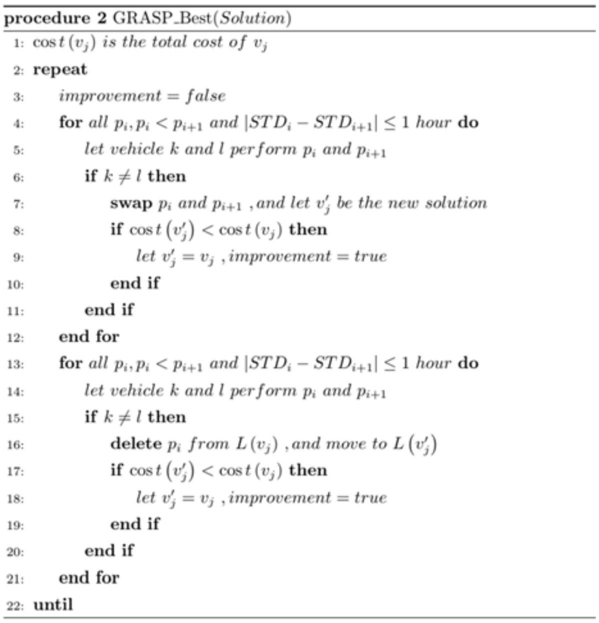
Figure 2. Pseudo-code for construting preliminary feasible solution



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procedure 2 GRASP_Best(Solution)
$\cos t(v_j)$ is the total cost of $v_j$
repeat
    $improvement = false$
    for all $p_i, p_i < p_{i+1}$ and $|STD_i - STD_{i+1}| \leq 1$ hour do
        let vehicle $k$ and $l$ perform $p_i$ and $p_{i+1}$
        if $k \neq l$ then
            swap $p_i$ and $p_{i+1}$ , and let $v'_j$ be the new solution
            if $\cos t(v'_j) < \cos t(v_j)$ then
                let $v'_j = v_j$ , $improvement = true$
            end if
        end if
    end for
    for all $p_i, p_i < p_{i+1}$ and $|STD_i - STD_{i+1}| \leq 1$ hour do
        let vehicle $k$ and $l$ perform $p_i$ and $p_{i+1}$
        if $k \neq l$ then
            delete $p_i$ from $L(v_j)$ , and move to $L(v'_j)$
            if $\cos t(v'_j) < \cos t(v_j)$ then
                let $v'_j = v_j$ , $improvement = true$
            end if
        end if
    end for
until
```

Figure 3. Pseudo-code for finding the optimal solution

Experimental Analysis

The paper simulation case aims at departure flight of an international airport in winter which has one runway. Aircraft number is 283 with three types (B, C and D). For different types, varies number of vehicles required for each aircraft and the efficiency of each vehicle is the same. The deicing time of the aircraft is determined by the speed of liquid and the quantity required by the aircraft. According to the airport floor plan, the distance and driving time between regions can be calculated. The speed of aircraft and vehicles on different parts of the apron is limited. The model is developed in Anylogic7 and the number of departure aircraft is described in Figure 4.

The results of model validation are as follows. The total deicing queue time and take-off delay time under four algorithms are shown in Figure 5. It can be seen that during the early peak period (6:30-8:00), the delay time is growing rapidly. Deicing queue delay time that outputs by GRASP algorithm has reduced to 1166.37min. Regardless of the total deicing delay time or the total take-off delay time, GRASP is superior to the other three algorithms. The average queue time for deicing is reduced from 56.75min to 7.55min. And the maximum deicing queue time is also reduced from 444.55min to 95.57min.

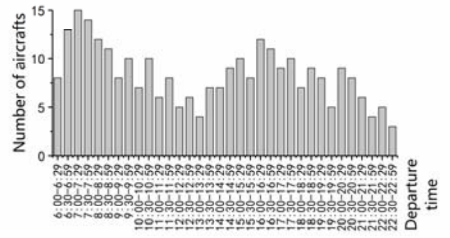

Figure 4. Distributing of departure time

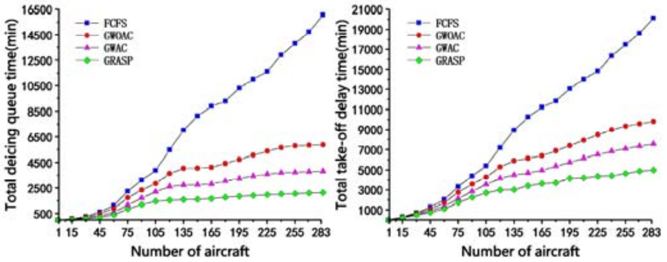

Figure 5. Total deicing queue time and total take-off delay time for aircrafts

Table 1. Workload and service times of vehicles before and after adjusting

Vehicle number	1	2	3	4	5	6	7	8	9
Workload before(min)	529	484	470	491	497	492	477	450	422
Service times before	85	77	78	81	85	82	75	63	55
Workload after(min)	492	475	484	480	474	470	468	463	460
Service times after	80	72	74	73	70	68	67	64	62

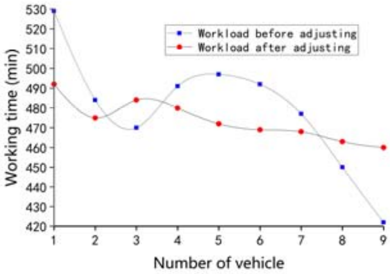

Figure 6. Workload before and after adjusting

At this time, the working hours and service times of each vehicle are shown in Table 1. It can be seen that the working time is not equal, v_1 and v_5 are used more frequently, v_8 and v_9 are less used. Put the workload of the deicing vehicle into the dispatching model, we can see that the number of times each car is used is relatively close, as shown in Table 1 and Figure 6. Meanwhile, the maximum number of waiting queues for aircraft under the GRASP algorithm has been reduced from 13 to 11 and further optimized.

Conclusion

In this paper, based on the scheduling modeling and simulation, the GRASP is used to select the deicing vehicle. After the simulation experiment based on one-day departure flights, it can be seen that GRASP is better than other comparison algorithms, which greatly reduces the queue and delay time. Experiments verify the effectiveness of the algorithm and provide a feasible solution.

Acknowledgment

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